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FINAL REPORT

19990358

**USING FERULIC ACID TO SELECT FUSARIUM
AND MIDGE-TOLERANT SPRING WHEATS**

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**"USING FERULIC ACID TO SELECT FUSARIUM AND MIDGE TOLERANT
SPRING WHEATS"**

FINAL REPORT

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ABSTRACT

Fusarium head blight (FHB) and the orange wheat blossom midge are potentially serious pests affecting wheat yields and grain quality in Saskatchewan. These two pests moved in tandem across the province from east to west during the 1990's. FHB-causing fungi produce mycotoxins which are undesirable in food and feed. It is likely that over time the tolerances for these toxins will become more stringent. One of the ways to deal with the negative impact of FHB and midge infestation is to breed resistant varieties of wheat. The primary objective of this study was to determine whether we could use naturally-occurring compound in the developing wheat bran (ferulic acid) to indirectly select for tolerance to these two problem pests. In order to do this we evaluated recently developed spring wheat experimental lines with putative tolerance to FHB or the wheat midge. We were able to demonstrate that it is possible to effectively select for increased ferulic acid content in spring wheat. However, in this study, we were not able to use the trait to select for increased resistance to FHB and wheat midge. We did demonstrate that it is possible to accelerate the development of fusarium head blight resistant spring wheat with a combination of doubled haploid technology, greenhouse increases and inoculated field nurseries. Using the breeding tools we could have cut the varietal development from 12 years down to six. The lines of FHB resistant spring wheat lines identified during the course of this study will provide the back-bone for future breeding efforts at the University of Saskatchewan.

EXECUTIVE SUMMARY

A series of three studies on spring wheat were conducted over a three year period in central and south-eastern Saskatchewan to determine whether ferulic acid can be used in indirectly selecting for resistance to fusarium head blight (FHB) and the wheat midge. In the first study, three populations resulting from divergent selection for ferulic acid content in earlier generations were evaluated for FHB reaction, agronomic performance and ferulic acid content in the immature and mature grain. In 2000 we did observe lower FHB incidences in the high ferulic acid group. In 2001 and 2002 we did not. Interestingly, cultivars such as Arin and Laura which we had found to be higher in ferulic acid content in previous research were also higher in this study. The Chinese cultivar Sumai3, the source of FHB resistance in a number of US and Canadian cultivars and parental lines, was also high in ferulic acid. Due to the mounting spring drought problems in 2001 and 2002 we were unable to detect midge injury at our primary testing site.

In a second study we evaluated a series of doubled-haploid spring wheat lines obtained from crosses between CWRS parents and Sumai3-based parental DNS wheat lines. We were able to select a number of lines with FHB resistance levels similar to those of Sumai3. Three DH lines were advanced to the Registration Test stage. One of these lines, 99FHB068, maintained a high level of resistance to FHB over four seasons of testing. This line did not make it to the varietal stage due to minor quality deficiencies. However, lines like 99FHB068 will become the back-bone of the Crop Development Centre FHB resistant spring wheat breeding effort over the next few years. The DH lines varied in grain ferulic acid level and these differences were repeatable

over years. However, FHB severity on the spike was not correlated with grain ferulic acid level, nor was the incidence of fusarium damaged kernels.

In the last study we evaluated three sets of experimental lines derived from partial backcrosses to CWRS wheat from the US winter wheat cultivar 'Seneca' a source of midge-resistance. In this study we again were able to detect significant genotypic differences in grain ferulic acid levels but little correlation with midge injury to the grain.

TECHNICAL REPORT

BACKGROUND AND OBJECTIVES

Two pests, the orange wheat blossom midge (insect) and fusarium head blight (FHB), a fungal disease, have spread in tandem across the black and dark brown soil zones of Saskatchewan over the last 10 years. Losses ascribed to these two pests are significant as they both reduce grain yield and more importantly, end-use quality.

Research conducted in eastern Canada suggests that the wheat midge can act as a carrier of soil-borne pathogens (Couture et al., 1995, Canadian Plant Disease Survey). Thus, the tandem movement of the two pests might be a result of this carrier effect in addition to having common optimal environmental conditions for their propagation. The Crop Development Centre has demonstrated that there is a correlation between ferulic acid content of the bran and midge infestation level. In addition we have developed an assay to estimate the level of ferulic acid in the grain (ADF project 96000043-44BV). Ferulic acid is one of the principal phenolic compounds that occur in the wheat bran. This naturally occurring compound has been implicated in resistance to the above pests in wheat as well as tolerance to storage insects in other crop species. Researchers in Minnesota (McKeehen, Busch and Fulcher, 1999; J. Agric. Food Chem. 47:1476-1482) published results linking resistance to FHB in spring wheat ("Evaluation of wheat *Triticum*

aestivum L. phenolic acids during grain development and their contribution to Fusarium resistance'') to ferulic acid content during grain-filling. Thus, this compound may act as source of resistance to both pests.

The wheat midge is estimated to reduce bread wheat yields by an average of 10%. This yield loss is equivalent to \$160 million per year. This sum does not take into account the penalties in lowered grades and the cost of insecticide where control measures are taken. The cost to durum growers is not included in the calculation. The potential of loss of markets is also significant as the midge damage reduces the baking quality of the grain. FHB is estimated to cost MB wheat growers \$60-70 million/year. The infestation level in SK is currently not at the same level but is increasing (CGC surveys, 1998-2001).

The primary objective of this study was to determine whether ferulic acid can be used as an indirect selection assay for tolerance to these two problem pests. In order to do this we evaluated recently developed spring wheat experimental lines with putative tolerance to FHB or the wheat midge. These lines were selected under pressure from these pests. Ferulic acid levels in immature and mature grain were measured and related to FHB infection and wheat midge (Sitodiplosis mosellana) infestation.

The final product from this research should be an indirect selection breeding tool for either one or both pests. The current methodology is highly labour-intensive. Secondly, breeding material with potential tolerance to the pests was challenged in the field. This could result in the identification of elite breeding material or lines for entry in the cultivar registration system.

EXPERIMENTAL METHODS

1. LINES SELECTED FOR HIGH VERSUS LOW LEVELS OF FERULIC ACID

Spring wheat lines were selected for high versus low ferulic (FER) acid grain content using the rapid visual assay (VIS) (Abdel-Aal et al., 2001) in 1998 and subsequently grown in unreplicated trials in 1999. The lines were from five populations. Three of the starting populations were relatively large while two were small. The two small populations were evaluated in the first year of the study only. The pedigrees of the three populations were:

X96.45 = AC Barrie/94M14

X96.48 = AC Elsa/94M14

X96.48 = AC Elsa/94M17

The 94M lines were the source of the higher grain ferulic acid content and are from crosses between Katepwa and Arin.

Immature grain FER content was determined for the experimental lines and their parents. Immature FER was determined via HPLC as outlined in Abdel-Aal et al. (2001). Ten spikes per plot were tagged at emergence. The spikes were harvested 14 days post emergence; this was circa 10 days post-anthesis. The harvested spikes were freeze-dried and placed in a freezer at -20 C until further processing. Immature spike collection and FER analyses were conducted on plots grown at Saskatoon in the absence of FHB infestation.

The degree of midge infestation was determined by harvesting 10 spikes per plot at maturity. The spikes were threshed using a rubber-roller deawner with the air turned off. The number of midge-damaged kernels were counted and data expressed as a percent of the total number of seeds in the sample. FHB infestation was measured in an inoculated nursery at the University of Manitoba Carman Research Farm (Dr. Anita Brule-Babel). An FHB index was calculated based on data from replicated (n=2) rows. This was done in 2000, 2001 and 2002.

In 2000, the selected lines were grown over two replicated (n=2) field trials at Saskatoon in 2000. As in 2000, a randomized complete block design (RCBD) was used for each of the tests. In 2001, the 65 lines from the three largest populations were grown in a replicated trial conducted at three sites. The three sites were the Kernen Crop Research Farm (KCRF), and Seed Farm (SF) of the University of Saskatchewan and the AAFC Experimental Farm at Indian Head, SK. In addition to the parents in the crosses, the cultivars Roblin (FHB susceptible control), Sumai3 (resistant control) and Arin (high ferulic acid content control) were included in the 2001 and 2002 trials. The 2002 trials were conducted at the same sites as in 2001. In addition to the three sites, replicated rows were grown at Saskatoon under irrigation. This was done in light of the severe drought at the beginning of the 2002 crop season. These replicated rows (n=2) were sampled for FER determinations in immature grain.

The experimental protocol for the yield trials was as follows:

Plots consisted of five rows, 3.7 m long spaced 20 cm apart. Fertilizer (11-51-0, N-P-K) was drilled with the seed at a rate of 50kg/ha. The seeding rate was 250 seeds m⁻². All yield trials at Saskatoon were established on fallow. Seeding dates were within the recommended window at each site. Weed control measures varied based on the spectrum of weeds within a given field and season. Plots were harvested with a plot combine and the grain dried to a moisture content of 10±1%.

FIELD EVALUATION OF DOUBLED-HAPLOID LINES WITH POTENTIAL FHB RESISTANCE

A series of doubled haploid spring wheat lines were developed using the maize pollination method (Suenaga K. and Nakajima, K. 1989) during the course of 1998. The lines that were selected for this study were screened for FHB reaction at Carman, MB in 1999. The pedigrees of those DH lines are as follows:

CDC Teal*2/ND2710

(99FHB3 to 99FHB298)

CDC Teal*2/MN2540
CDC Teal/Bacup//CDC Teal/MN93413
AC Elsa/ND2710//CDC Teal/Bacup
CDC Teal/ND2710//CDC Teal/MN93413

(99FHB299 to 99FHB318)
(99FHB325 to 99FHB343)
(99FHB350 to 99FHB371)
(99FHB374 to 99FHB412)

The susceptible parents in these crosses are CDC Teal and AC Elsa. The resistant parents are ND2710, MN2540, MN93413 and Bacup.

A total of 100 doubled-haploid spring wheat lines were evaluated in replicated trials ($n=2$) at three sites in 2000 (Carman, MB; Seed Farm and Kernen Farm). The DH lines were split into two trials. The experimental lines were also entered into an inoculated nursery at Carman and scored for FHB damage at mid-grain fill (2000-2002). Midge damage assessments were conducted on plots of the check cultivars from the Kernen Farm in 2000-2002; however midge damage levels were minimal and data collection was curtailed. In 2001, 48 selected DH lines were grown at the Kernen Farm and at two seeding dates at Carlyle, SK. In 2002, the same lines were grown at the Seed Farm and at two seeding dates at Carlyle. In each year the Carlyle trials were seeded at least 15 days apart. This was done to maximize the opportunity for host-pathogen-environment nicking.

The yield trial protocols for this experiment were the same as described in the previous section.

The plots at Carlyle were rated for FHB infection on a 1-5 scale, where 1 = no injury. At Carlyle, 10 spikes per plot were harvested at maturity in 2001. The spikes from the second seeding date were assessed for FHB and midge injury, as this was the seeding date for which the most spike injury was noted.

Many of the lines first tested in 2000 had FHB infection levels that were much lower than those of AC Elsa and CDC Teal, the controls. Some lines had infection levels of 2% compared to 35% for the controls. Lines with low FHB levels and acceptable agronomic performance were advanced for routine quality evaluation.

A new set DH lines ($n=700$) were generated in 2000-2001. A majority of these were increased in New Zealand during the winter of 2000/2001 and then grown in unreplicated trials in 2001. A majority of the lines were also tested in the FHB nursery at Carman in 2001. The remaining DH lines were increased in the greenhouse during the summer of 2000. These DH lines were meant to incorporate FHB resistance into an acceptable agronomic background. Approximately 5% of the lines survived the FHB challenge and 40 were grown in replicated yield tests in 2002. In addition, the lines were tested in the 2002 Carman FHB nursery

FIELD EVALUATION OF SPRING WHEAT LINES WITH POTENTIAL MIDGE RESISTANCE

Thirty-one spring wheat lines resulting from partial (BC_2) backcrossing of the midge-resistant winter wheat cultivar 'Seneca' were evaluated at five locations (Kernen Farm, Seed Farm, Goodale Farm, Indian Head and Swift Current) in a two-replicate trial in 2000. Ten spikes were harvested 10 days post-anthesis at the Seed Farm site and freeze-dried to allow immature FER

determination. At maturity 10 spikes per plot were harvested to assess midge-damage from the Indian Head site. Midge infestation levels were very low.

The 31 lines were selected from 1,000 lines evaluated for midge damage, agronomic and quality traits in unreplicated tests at the Kernen Farm in 1999. These lines had previously been grown in an irrigated rust nursery in 1999 and screened for midge injury. The 31 lines came from four crosses:

AC Barrie*3/Seneca	(7 lines)
AC Barrie//CDC Teal*2/Seneca	(3 lines)
CDC Teal*3/Seneca (DH lines)	(20 lines)
CDC Teal*2/Seneca	(1 line)

Seneca is the source of midge resistance (Barker and McKenzie, 1996) in these spring wheat populations.

In 2000, a new set of BC-derived lines (n=600) was grown in unreplicated tests at the Kernen Farm. A series of DH lines were tested in a rust nursery in 2000. Many of the lines were susceptible to rust. The remaining lines were screened for midge damage. Of these these lines, 32 were re-tested in 2001. The lines were from two populations:

AC Barrie*2//CDC Teal*2/Seneca	(12 lines)
CDC Teal*4/Seneca	(20 lines)

The 2001 experiment was conducted at four sites: Kernen Farm, Seed Farm, Goodale Farm and Indian Head Experimental Farm.

In 2002, a third set of experimental lines was evaluated for midge resistance and ferulic acid content. These lines were were tested at four sites: Seed Farm (Early-seeding); Seed Farm (late-seeding), Scott AAFC and Indian Head AAFC. The site at Scott was lost due to drought and sawfly infestation. The Seed Farm trials were seeded three weeks apart. The lines tested were selected from the following populations:

Teal*2//DHT/S-10	(1 line)
AC Elsa*2//DHT/S-10	(9 lines)
CDC Bounty/3/AC Elsa//DHT/S-10	(9 lines)
CDC Bounty/BW277	(2 lines)
CDC Teal/BW277	(2 lines)
AC Intrepid/BW277	(2 lines)

All these lines were doubled haploids. In addition, the parental line DHT/S-10 is a DH line. The yield trial protocols for this experiment were the same as described in the previous section.

RESULTS

LINES SELECTED FOR HIGH VERSUS LOW LEVELS OF FERULIC ACID

Immature ferulic acid (FER) content was determined for all the experimental lines and their parents from the SF and KCRF trials in 2000 (Table 1). Immature FER was determined via HPLC as outlined in a recently published paper by Abdel-Aal et al. (2001). Spikes were harvested approximately 10 days post-anthesis and freeze-dried. FHB infestation was measured in an inoculated nursery at Carman, Manitoba. Divergent selection did not affect yield and other agronomic traits to a significant extent. Midge damage was low for both low and high FER lines. Of interest, is the fact that high FER lines generally had, on average, half the level of FHB than did low FER lines in two out of the three populations. In those cases the decrease in FHB infestation was statistically significant. In both populations (X96.45 and X96.48) where immature grain FER was measured in 2000, initial selection via VIS resulted in significant differences. In other words VIS selection on mature grain resulted in FER differences in immature grain. Thus, selection for higher FER levels, reduced FHB infestation in 2000. However, low midge infestation levels that year did not allow us to detect any differences among FER groupings.

As was the case in 2000, divergent selection did not affect yield and other agronomic traits to a significant extent in either 2001 or 2002. Unlike, 2000, we were unable to detect significant differences in FHB infestation between low and high ferulic acid lines in 2001 or 2002. However, the trend was still one of reduced FHB with higher ferulic acid in immature grain. This study did demonstrate that it is possible to breed for altered phenolic acid levels in the wheat grain. However, we were unable to show that selecting for higher ferulic acid levels in the bran conferred improved resistance to FHB or wheat midge. The German cultivar 'Arin' had a higher FER level, confirming our earlier results (Abdel-Aal et al., 2001). The cultivar Sumai3 had an even higher level of mature grain FER than did Arin. McKeehen et al. (1999) had previously reported that Sumai3 was high in ferulic acid content. Thus our results were consistent with those previously reported in the literature. Sumai3 had very low levels of FHB infestation in both years it was evaluated,

FIELD EVALUATION OF DOUBLED-HAPLOID LINES WITH POTENTIAL FHB RESISTANCE

2000 experiments:

Many of the DH lines evaluated at Carman, MB in 2000 had FHB infection levels that were much lower than those of AC Elsa and CDC Teal, the controls. Some lines had infestation levels of 2% compared to 35% for the controls (Table 2). Combined over the two field trials, 19 lines had infection levels of less than 5%. Lines with low FHB levels and acceptable agronomic performance were advanced for quality evaluation. Two of those lines, 99FHB068 (BW304) and 99FHB359 (BW305), were grown in the Central Bread Wheat Cooperative Test in 2001. The line 99FHB068 ranked first for FHB score in the Cooperative Test and was retained for quality evaluation. 99FHB068 was faulted for having too heavy a kernel and weaker dough properties. We retested 99FHB68 in 2002 and it again had a very high level of FHB resistance. This demonstrated that it is possible to transfer FHB resistance into a relatively susceptible parental background.

The second 2001 Coop entry, 99FHB359, was dropped due to weak straw, intermediate FHB score and poor bunt reaction. A third line, 99FHB226, was entered into a pre-cooperative test (the CBW'B' Test). This line was retained after quality evaluation and tested as BW333 in the 2002 Central Bread Wheat Cooperative Test. BW333 gave a moderately susceptible reaction to FHB in 2002 and was thus dropped. Another three 99FHB series lines (99FHB264, 99FHB297 and 99FHB400) were tested in the 2002 Central Bread Wheat 'B' Test. Two of the lines (99FHB264 and 99FHB400) had a moderate level of resistance to FHB while the third did not. Thus, six lines were entered in the cultivar registration system and three maintained acceptable, if not superior, levels of FHB resistance.

2001-2002 experiments

Doubled haploid lines selected from the two trials grown in 2000 were grown in a single experiment in 2001 and 2002 (Table 3). As was the case in 2000, many of the lines had FHB infection levels that were much lower than those of the CWRS controls (Table 4). Of the 47 lines, 18 were highly resistant in both 2000 and 2001. However, the inter-year correlation for FHB ratings ($r=0.12$) was low, indicating that multi-year testing is essential to identify stable, FHB resistant lines. Sumai-3, the resistance source in most breeding programs, was included in the trial, as were resistant lines from North Dakota and Minnesota (ND and MN designations) and the cultivar 'Bacup'. The latter were parents in the development of some of the DH lines. These parental lines were, on average, 25% lower yielding than AC Barrie. MN93413 ('McVey') was the exception, yielding 19% higher than AC Barrie (Table 3). However, McVey was 3.7% lower in protein content. Sumai*3 yielded 38% less than AC Barrie, CDC Teal and Laura. The low yields of the parental material highlight the challenge in incorporating FHB resistance into an adapted background. A majority of the DH lines were within the envelope for agronomic performance (Table 3).

The DH lines exhibited a 40 to 50% range in ferulic acid content in both the immature and mature grain (Table 4). The cultivar Bacup had the highest ferulic acid levels in the experiments conducted in 2001 and 2002. The cultivar Sumai*3 tended to have a higher level of ferulic acid. When mature spikes from the 2001 Carlyle site were quantified for seed damage due to FHB and midge, we found that there were significant differences among wheat genotypes. The proportion of FHB-damaged seed ranged from 0.0 to 7.4% while the percentage of midge-damaged ranged from 1.9 to 17.4% (Table 4). The percent of seed that exhibited both midge and FHB injury ranged from 0.4 to 25.3% (Table 4). If the data is viewed from a different perspective – % undamaged seed; we found that the range was from 64.8 to 96.9%. The parental lines ranged from 87.5 to 94.8% undamaged seed while the check cultivars ranged from 78.9 to 93.5%. Interestingly, the cultivar AC Elsa, which is considered susceptible to FHB based on spike injury symptoms, had the least disease and insect damaged seed in this experiment (Table 4).

The inter-year correlation (2001 versus 2002) for FHB index (Carman data) was $r = +0.43$. This was markedly better than the 2000 versus 2001 correlation, but still low from a plant breeding efficiency perspective. The inter-year correlation for FER content was quite high ($r=0.84^{**}$), indicating good repeatability for the ferulic acid content trait. However, based on the data presented in Table 4 the average correlations between immature or mature grain FER and FHB injury were very low and statistically non-significant. When the five lines with the lowest and

highest levels of FHB infection were compared (an 8-fold difference) we did not observe any differences in ferulic acid content between the two groups. We did detect a weak correlation ($r = -0.2$) between immature grain FER levels and 2001 midge damage (Carlyle samples).

FIELD EVALUATION OF SPRING WHEAT LINES WITH POTENTIAL MIDGE RESISTANCE

In 2000, although there was a two-fold variation in midge-damage (7 to 16%), none of the lines was immune or highly resistant to the wheat midge (Table 5). The lines differed statistically in immature FER concentration ($P=0.06$). The experimental lines ranged from 234 to 291 mg/100g FER. The cultivar Laura had the highest level of FER in this experiment (297mg/100g). There was a weak negative correlation between immature FER and prevalence of midge injury ($r = -0.27$). Four lines were retained for quality testing on the basis that they had reduced midge damage levels and acceptable agronomic performance. One of the lines (W00073) was advanced to the Western Bread Wheat 'B' Test grown at seven sites in 2001. W00073 yielded 10% less than AC Barrie in 2001. Hence, it was dropped from further testing.

Due to the severe drought in 2001, only trace levels of midge damage were observed at the SF and KCRF sites. Indian Head, which was a high infestation site in 2000, was also affected by drought, hence midge-damage was minimal. On average, grain yields in 2001 were reduced by 30% relative to 2000 (Table 6). Only trace amounts of midge damage were observed on the controls, hence further analysis was discontinued for that variable. The lines differed in immature FER concentration ($P=0.05$) at each of two sites. Of the check cultivars, Laura had the highest FER concentration (240mg/100g). The experimental lines ranged from a low of 194 to a high of 251 mg/100g FER. This relative difference among genotypes (30%) was similar to that observed in 2000.

One line (W01242) was advanced to the 2002 Western Bread Wheat 'B' Test. This line yielded 8% less than AC Barrie in 2002 and was thus withdrawn from further evaluation.

In 2002 a third series of lines was tested (Table 7). These lines were all doubled-haploids aimed at increasing the speed of introgressing midge resistance into a CWRS wheat background. Samples from the Indian Head site were assessed for midge injury. The experimental lines ranged from 3.8 to 15.6% midge-damaged seed. The FER levels ranged from 187 to 261 mg/100g (immature grain) and 52.3 to 68.6 mg/100g (mature grain) for the 31 experimental lines. The 2002 correlations between FER and midge damage were low and statistically non-significant.

CONCLUSIONS

Through the use of double-haploid technology we were able to develop lines of red spring wheat with high levels of resistance to fusarium head blight (FHB) and enter them in Registration Tests within a period of three years. From a total of approximately 400 initial DH lines, 20 were highly resistant to FHB. Half a dozen of these lines were entered into the Registration Testing stream. The most promising line (99FHB068) provided consistently low FHB scores over a

period of three years in this study and two additional years outside of this study. 99FHB068 (BW304) yielded 8% higher than its FHB resistance donor parent (ND2710) and was earlier maturing and shorter-strawed. 99FHB068 did not reach the cultivar stage due to quality weaknesses. However, this line is being used as a parent in the CDC spring wheat program. Two experiments (Divergent selection; Midge-tolerant wheat lines) demonstrated that it is possible to select for increased levels of ferulic acid and that this trait is repeatable over environments. However, we were not able to establish a link between increased ferulic acid content and decreased FHB or midge injury to wheat kernels. This suggests that the experimental material used in this study was characterized by FHB resistance mechanisms not involving ferulic acid as a major resistance mechanism. Having said that, there were a number of FHB resistant lines (eg 'Bacup') with quite elevated levels of ferulic acid in the grain.

IMPACT ON SASKATCHEWAN AGRICULTURE

This project demonstrated that it is possible to accelerate the development of fusarium head blight resistant spring wheat with a combination of doubled haploid technology, greenhouse increases and inoculated field nurseries. Using the breeding tools we could have cut the varietal development from 12 years down to six. The lines of FHB resistant spring wheat lines identified during the course of this study will provide the back-bone for future breeding efforts at the University of Saskatchewan.

References

Abdel-Aal, E.S.M, Hucl, P. Sosulski, F.W.; Graf, R., Gillot, C. and Pietrzak, L. 2001. Screening spring wheat for midge resistance in relation to ferulic acid content. J. Agr. Food Chem. 49:3559-3566.

Barker, P.S. and R.I.H. McKenzie. 1996. Possible sources of resistance to the wheat midge in wheat. Can. J. Plant Sci. 76:689-695.

Mc Kee hen J. D., Busch. R. H. and R. G. Fulcher, 1999. Evaluation of wheat (*Triticum aestivum* L.) phenolic acids during grain development and their contribution to Fusarium resistance. J. Agric. Food Chem. 47:1476-1482.

Suenaga K. and Nakajima, K. 1989. Efficient production of haploid wheat (*Triticum aestivum*) through crosses between Japanese wheat and maize (*Zea mays*). Plant Cell Reports 8: 263-266.

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ITEM "B". Deviations from original workplan -- NIL

ITEM "C". Successful data collection in each of three years, with exception of midge injury

ITEM "D". Equipment-NIL.

ITEM "E".

Personnel:

2000

N.Y. Jay	Tech	Aug 1 -- Dec 31, 2000	40%
V. Spilchuk	Casual	Nov 8 -- Dec 31, 2000	100%
M. Doecker	Casual	Nov 27 -- Dec 15, 2000	100%

2001

H-S. Han	PRA	Jan 1 -- Dec 31, 2001	33%
N.Y. Jay	Tech	June 1 -- Dec 31, 2001	100%
A. Eichendorf	Summer assistant	May 1 -- Sept 1, 2001	100%
V. Spilchuk	Casual	April 1 -- Dec 31, 2001	60%
M. Grieman	Tech	May 1 -- July 1, 2001	100%

2002

S. Zou	Tech	July 1 -- Dec 31, 2002	100%
K. Jackle	Tech	October 1 -- Dec 31, 2002	100%
M. Cardenas	Tech	October 1 -- Dec 31, 2002	50%
V. Spilchuk	Casual	Dec 20-23, 2002	100%

Other
contributors:

P. Huel	April 1, 2000 -- Dec 31, 2002	5%
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ITEM "F". Expense statement -- attached

Table 1. Field evaluation of spring wheat lines subjected to divergent selection (high vs. low) for ferulic acid content of the grain, Saskatoon 2000-02.

Entry ²	Type	N	Grain yield (kg/ha)			Spike emergence (d)			Physiological maturity (d)			Plant height (cm)		Test weight (kg/hL)	
			2000	2001	2002	2000	2001	2002	2000	2001	2002	2000	2002	2000	2002
X96.45	Low	14	4229	2540	3086	58.6	58.4	57.8	96.6	89.6	98.1	100.7	83.0	77.7	77.6
	High	14	4225	2515	3120	59.5	59	58.4	96.9	89.9	99.0	102.7	82.1	78.1	77.7
X96.48	Low	9	4312	2493	2910	57.7	57.8	56.0	96.7	89.2	97.4	102.9	82.9	78.4	77.0
	High	8	4387	2528	2991	59.7	59.3	58.0	97.6	90.1	98.8	105.0	82.5	78.0	77.1
X96.49	Low	10	3893	2463	2944	57.5	57.1	56.3	96.2	87.8	97.2	101.7	82.4	77.8	77.1
	High	10	3915	2436	2889	58.6	58	57.2	95.9	88.4	97.9	101.1	82.5	77.5	76.8
Checks:															
AC Barrie	-	-	4087	2631	2810	56.3	56.8	55.0	94.3	87.5	92.3	96.5	76.8	78.7	77.0
AC Elsa	-	-	4293	2379	3216	56.2	57.0	57.0	95.6	86.8	95.8	95.5	75.8	78.2	79.1
AC Majestic	-	-	3865	-	-	58.0	-	-	96.7	-	-	95.5	-	78.3	-
94M14	-	-	4242	2660	3097	62.3	61.5	60.3	98.1	92.3	102.0	111.0	81.0	78.3	76.2
94M17	-	-	4001	2337	2900	58.7	58.0	57.5	97.4	90.5	98.8	105.5	82.8	79.5	77.0
Arin	-	-	3705	2291	3368	61.4	60.0	61.0	99.7	91.5	102.5	105.5	81.5	84.0	78.7
Roblin	-	-	-	1888	2230	-	53.3	53.3	-	84.3	90.8	-	73.0	69.0	76.9
Sumai 3	-	-	-	1808	1842	-	58.0	56.0	-	89.3	101.5	-	85.5	72.3	76.2

Table 1. Continued...

Entry ²	Type	N	1000-kernel weight (g)		Ferulic acid content- 10DPA (mg/100g)				Midge damage (%)		Fusarium head blight index (0-100%)		Rapid visual assay	Ferulic acid content- maturity (mg/100g)	
			2000	2001	2002	2000	2001	2002	2000	2001	2000	2001	2000	2002	2002
X96.45	Low	14	32.5	-	36.9	215.0	218.5	215.7	4.6	-	18.0	28.4	22.6	2.8	65.9
	High	14	32.7	-	36.4	239.0	231.6	224.0	5.9	-	8.0	26.7	23.4	4.6	72.5
X96.48	Low	9	33.6	-	35.4	233.0	226.8	226.5	5.4	-	23.0	37.2	30.3	2.6	73.8
	High	8	32.8	-	35.0	246.0	226.1	222.6	4.6	-	19.0	30.9	31.9	4.4	71.9
X96.49	Low	10	32.6	-	35.1	-	212.5	214.6	3.8	-	24.0	27.8	20.6	2.4	66.7
	High	10	31.0	-	33.3	-	220.4	220.2	4.4	-	14.0	23.7	22.3	4.4	71.0
Checks:			ns		**		ns	ns	**		**	ns	ns	***	*
AC Barrie		-	29.9	-	34.5	243.0	232.9	223.7	8.4	-	-	53.1	31.3	-	63.7
AC Elsa		-	31.7	-	39.4	266.0	229.0	219.4	9.8	-	-	21.5	32.5	-	57.9
AC Majestic		-	33.4	-	-	211.0	-	-	3.0	-	-	-	-	-	-
94M14		-	31.6	-	36.3	245.0	226.6	208.8	1.8	-	-	52.5	22.0	-	72.1
94M17		-	36.2	-	37.4	-	201.7	206.6	-	-	-	29.3	12.8	-	57.6
Arin		-	33.7	-	37.0	-	244.5	232.4	-	-	-	22.0	11.9	-	75.1
Roblin		-	-	-	37.1	-	241.1	238.7	-	-	-	46.4	36.5	-	54.7
Sumai 3		-	-	-	34.5	-	236.9	236.9	-	-	-	4.6	0.1	-	80.9

² Cross number X96.45=Barrie/94M14; X96.48=Elsa/94M14; and X96.49=Elsa/94M17.

*, **, *** Significant at the 0.10, 0.05 and 0.01 probability levels, respectively; ns, not significant.

Table 2. Field evaluation of FHB DH spring wheat lines in 2000

Entry	Yield (kg/ha)	Spike emergence (d)	Physiological maturity (d)	Plant height (cm)	Lodging score (1-9)	Test weight (kg/hL)	1000-Kernel weight (g)	Fusarium head blight index (0-100%)
Test 1:								
Barrie	3568	56.0	91.6	93.3	2.0	76.8	30.7	-
Laura	3772	56.5	94.0	97.3	3.5	77.5	32.0	-
Elsa	3732	56.0	92.3	91.3	3.5	76.9	31.1	35
Teal	3837	55.2	92.8	92.0	3.0	76.2	31.4	38
Statistics for DHs								
No. of lines	68	68	68	68	68	68	68	68
Mean	3561	55.6	93.9	97.1	3.2	76.5	31.4	13.3
Standard deviation	425	1.6	1.4	6.0	1.0	2.4	3.0	7.0
Standard error	52	0.2	0.2	0.7	0.1	0.3	0.4	0.8
Minimum	1948	52.0	91.5	92.0	2.0	61.6	21.5	2.0
Maximum	4306	61.7	97.5	110.3	7.0	79.2	36.5	30.0
Test 2:								
Barrie	3353	55.9	94.3	97.8	2.5	76.4	30.5	
Laura	3761	56.8	96.4	96.6	3.5	76.2	30.2	
Elsa	3874	55.7	93.9	95.1	4.0	76.3	30.9	
Teal	3913	55.5	92.2	93.9	2.9	75.8	31.7	
Statistics for DHs								
No. of lines	32	32	32	32	32	32	32	32
Mean	3689	55.7	94.6	94.8	3.0	76.4	32.1	7.7
Standard deviation	309	1.5	1.4	4.6	0.7	1.9	3.1	4.5
Standard error	55	0.3	0.3	0.8	0.1	0.3	0.5	0.8
Minimum	2855	52.4	91.5	85.1	1.9	69.6	27.1	2.0
Maximum	4139	58.1	97.7	105.2	5.0	80.8	39.9	20.0

Table 3. Field evaluation of FHB DH spring wheat lines in 2001 and 2002

Entry	Yield (kg/ha)	Spike emergence (d)	Physiological maturity (d)	Plant height (cm)	Test weight (kg/hL)	1000-kernel weight (g)
AC Barrie	2476	55.3	88.8	59.5	79.9	34.5
Laura	2401	55.0	89.3	54.0	79.3	34.6
AC Elsa	2273	55.5	89.0	59.8	80.3	37.5
CDC Teal	2523	54.0	87.0	64.5	79.0	35.2
99 FHB-30	1754	54.8	89.8	62.5	77.6	34.4
99 FHB-64	2301	56.0	90.5	66.8	80.8	38.3
99 FHB-68	2304	53.3	88.3	70.3	80.1	38.0
99 FHB-72	2235	54.0	87.5	64.8	78.9	33.6
99 FHB-103	2133	53.0	87.0	58.5	80.1	37.0
99 FHB-105	2003	52.8	83.5	60.3	76.2	34.3
99 FHB-124	1969	52.5	84.5	61.5	77.8	34.6
99 FHB-130	2084	51.8	86.5	66.0	80.1	39.0
99 FHB-134	2226	53.5	88.3	64.0	79.7	31.0
99 FHB-143	2439	54.5	89.5	72.8	79.5	34.0
99 FHB-162	2098	52.8	86.3	62.3	77.5	33.6
99 FHB-164	2417	54.5	88.8	66.8	79.1	35.1
99 FHB-224	2059	54.3	89.8	67.5	79.3	36.9
99 FHB-234	1943	53.0	90.8	61.8	79.8	35.1
99 FHB-264	2178	54.0	89.8	64.3	79.5	36.4
99 FHB-275	2267	54.3	88.3	67.0	79.4	33.9
99 FHB-289	2147	54.0	87.8	67.8	79.5	35.8
99 FHB-290	2225	54.3	87.0	67.8	79.7	37.5
99 FHB-292	2222	55.3	88.5	66.8	80.3	33.1
99 FHB-297	2153	53.3	87.3	65.8	78.4	32.4
99 FHB-298	2166	53.3	88.0	65.3	78.4	34.9
99 FHB-305	2258	53.8	86.8	63.8	79.7	32.4
99 FHB-326	2312	53.3	88.5	62.3	77.9	36.3
99 FHB-333	2525	57.0	93.8	59.0	80.0	34.8
99 FHB-336	2392	54.0	89.5	64.3	77.7	37.0
99 FHB-338	2744	54.8	91.0	64.8	80.9	37.7
99 FHB-343	2642	56.3	91.5	61.5	79.0	35.9
99 FHB-350	2722	58.0	92.8	65.3	79.5	39.2
99 FHB-353	2463	54.5	90.5	70.0	78.1	34.6
99 FHB-354	2167	55.8	89.8	62.8	81.2	32.1
99 FHB-359	2309	55.0	87.8	56.8	77.3	38.9
99 FHB-363	2296	53.5	86.3	66.5	80.3	38.2
99 FHB-366	2384	53.5	90.3	67.3	80.9	43.8
99 FHB-379	2192	55.0	90.8	64.0	79.3	33.1
99 FHB-384	2483	56.0	98.3	70.0	79.2	37.0
99 FHB-385	2531	56.3	89.5	68.0	80.7	38.1

99 FHB-387	2447	54.8	91.8	64.0	79.9	37.9
99 FHB-394	2050	55.0	88.5	63.0	78.2	37.0
99 FHB-397	1970	52.8	89.3	57.0	80.7	33.7
99 FHB-399	2196	54.5	86.5	61.0	78.5	36.7
99 FHB-400	2438	55.3	89.0	58.8	77.8	34.0
99 FHB-404	2165	55.3	89.8	54.8	79.2	32.3
99 FHB-405	2664	54.8	89.0	63.5	79.5	39.8
99 FHB-406	2385	54.8	88.8	62.3	79.8	39.3
99 FHB-407	2676	55.8	91.0	65.3	80.4	37.6
99 FHB-409	2276	53.5	88.3	64.3	78.4	37.7
99 FHB-412	2785	56.5	91.5	66.5	80.3	37.2
ND 2764	1904	55.5	91.3	68.5	78.2	28.9
ND 2736	1876	54.5	94.5	64.8	79.1	35.0
ND 2710	2137	53.5	90.0	79.5	79.9	39.2
MN 2540	1971	55.5	92.5	58.3	82.4	33.5
MN 93413	2934	58.5	92.5	58.0	80.2	38.8
SUMAI*3	1538	56.8	94.0	66.5	77.7	32.4
BACUP	1457	52.3	88.8	61.3	81.3	36.1
No. of sties	6	2	2	2	1	1
LSD (0.05)	380	1.6	3.6	4.8	1.2	3.0

Table 4. Evaluation of FHB DH spring wheat lines for fusarium head blight tolerance, ferulic acid content, and midge tolerance in 2001 and 2002 (Test 1).

Entry	Fusarium head blight rate (1-5)		Fusarium head blight index (0-100%)	Ferulic acid content-10DPA (mg/100g)		Ferulic acid content-maturity (mg/100g)	Midge-FHB damaged seed (%)	Midge damaged seed (%)	FHB damaged seed (%)	Non-damaged seed (%)
	2001	2002		2001	2002					
AC Barrie	3.0	3.3	56.0	221.5	235.1	61.5	6.7	5.1	5.6	82.7
Laura	2.4	2.8	42.0	250.4	239.9	72.7	13.6	6.4	7.0	73.0
AC Elsa	2.5	2.0	42.0	209.7	227.1	62.7	1.5	3.7	1.2	93.5
CDC Teal	3.0	3.3	48.0	204.9	201.9	50.2	6.8	8.6	5.7	78.9
99 FHB-30	2.1	3.8	11.9	215.1	208.9	52.8	5.1	5.0	2.5	87.4
99 FHB-64	2.3	1.5	6.4	196.3	189.8	49.1	3.3	6.8	2.6	87.3
99 FHB-68	2.6	3.5	5.8	193.8	213.6	47.6	16.2	10.2	5.8	67.8
99 FHB-72	3.0	3.3	17.0	186.7	195.1	49.0	1.8	7.8	0.0	90.4
99 FHB-103	2.4	3.0	12.8	183.2	185.5	44.9	6.6	3.5	2.8	87.1
99 FHB-105	3.5	3.8	14.5	197.7	199.1	49.7	2.7	6.7	2.5	88.2
99 FHB-124	3.6	3.3	14.0	214.7	215.4	53.8	1.9	6.9	2.5	88.6
99 FHB-130	3.0	3.3	6.0	223.7	207.4	62.9	7.1	4.1	7.4	81.5
99 FHB-134	2.4	3.0	5.5	196.3	192.9	54.1	2.9	17.4	1.4	78.3
99 FHB-143	2.3	2.3	26.3	213.4	219.3	54.6	0.6	7.0	0.4	92.1
99 FHB-162	3.0	3.5	12.0	209.6	204.4	54.8	3.7	9.6	0.6	86.1
99 FHB-164	2.3	3.3	11.0	197.5	200.0	53.6	5.3	5.7	2.9	86.2
99 FHB-224	2.4	3.0	42.0	181.1	187.0	45.9	4.5	5.2	2.5	87.7
99 FHB-234	3.0	2.5	16.0	214.8	204.0	49.7	5.6	4.5	0.7	89.2
99 FHB-264	2.8	3.0	3.9	189.5	221.9	56.2	6.6	3.3	1.4	88.7
99 FHB-275	3.1	3.0	38.5	216.6	222.9	54.0	3.6	6.7	3.4	86.3
99 FHB-289	2.6	3.0	18.0	213.7	209.1	60.0	25.3	5.9	4.0	64.8
99 FHB-290	2.6	2.3	21.0	210.0	213.1	57.6	7.4	8.3	2.4	82.0
99 FHB-292	1.6	2.5	17.5	189.0	197.9	49.1	1.1	5.7	0.8	92.4
99 FHB-297	3.4	4.0	32.0	212.1	211.7	52.6	4.8	4.8	1.8	88.5
99 FHB-298	3.8	3.5	32.5	205.4	206.9	54.1	0.9	3.5	2.0	93.6
99 FHB-305	2.5	2.8	31.3	206.7	235.1	48.5	9.8	8.4	3.2	78.5
99 FHB-326	2.5	3.0	2.9	236.7	242.9	47.8	3.7	3.7	3.2	89.4
99 FHB-333	1.5	2.0	16.5	229.1	226.2	53.4	4.3	9.0	1.3	85.4
99 FHB-336	1.9	2.8	6.4	209.9	220.8	50.9	6.4	8.6	6.9	78.1
99 FHB-338	2.5	3.8	21.0	214.9	235.0	58.4	9.2	4.7	2.9	83.2
99 FHB-343	1.8	2.5	4.2	217.2	227.2	51.7	2.9	7.4	1.1	88.7
99 FHB-350	1.3	2.0	6.3	187.1	189.2	58.3	0.4	14.3	0.4	84.8
99 FHB-353	1.6	2.8	0.3	216.9	220.4	61.5	1.0	1.9	0.3	96.9
99 FHB-354	1.8	2.5	15.5	206.8	206.3	59.9	1.8	7.1	0.8	90.3
99 FHB-359	2.4	3.0	15.5	255.1	249.0	55.2	18.1	9.3	4.8	67.8
99 FHB-363	2.3	2.8	13.4	180.7	202.2	53.8	3.1	9.3	4.5	83.1

99 FHB-366	2.6	3.3	11.3	240.7	236.1	63.5	4.9	7.6	1.3	86.2
99 FHB-379	1.9	2.5	3.5	223.2	206.0	58.2	2.4	10.5	0.8	86.3
99 FHB-384	2.0	1.8	38.3	231.6	253.5	58.3	14.2	7.8	6.1	71.8
99 FHB-385	2.4	2.8	5.0	197.3	200.7	55.2	1.6	9.8	0.0	88.6
99 FHB-387	2.3	2.8	9.8	233.7	227.3	56.0	4.1	4.6	2.3	89.0
99 FHB-394	2.8	3.0	23.0	209.9	211.3	55.3	7.1	2.7	4.4	85.9
99 FHB-397	2.5	4.0	6.8	228.3	212.6	50.5	1.4	6.3	0.3	92.0
99 FHB-399	2.9	3.3	12.8	197.6	196.5	55.0	3.4	5.5	5.8	85.3
99 FHB-400	2.5	3.0	9.8	269.7	222.2	53.4	3.2	5.0	0.7	91.1
99 FHB-404	2.1	2.3	12.0	213.7	234.2	68.5	2.9	6.2	2.3	88.5
99 FHB-405	2.1	2.5	10.8	168.7	183.4	45.7	3.0	10.4	3.6	83.1
99 FHB-406	2.5	3.0	24.8	214.9	199.0	49.7	0.4	9.0	1.5	89.0
99 FHB-407	2.0	2.0	47.3	248.6	254.1	56.7	3.1	8.5	1.7	86.7
99 FHB-409	2.4	2.8	7.0	191.1	211.3	52.5	7.1	6.5	3.5	82.9
99 FHB-412	2.0	1.5	17.8	201.5	197.0	46.4	1.8	11.6	1.8	84.8
ND 2764	1.4	2.0	0.3	239.0	234.3	67.9	1.6	10.1	0.7	87.5
ND 2736	2.1	2.8	0.3	214.0	211.4	62.0	0.2	7.7	0.2	91.9
ND 2710	1.9	3.0	0.7	198.7	205.3	53.6	1.6	5.1	2.1	91.2
MN 2540	2.6	1.2	4.4	244.6	241.9	61.7	1.3	3.9	0.3	94.5
MN 93413	1.4	2.0	4.9	185.1	182.0	61.6	1.3	5.4	0.6	92.6
SUMAI*3	1.6	5.0	0.3	245.5	234.8	68.1	0.6	6.3	1.0	92.2
BACUP	2.5	3.5	4.5	300.1	268.2	62.1	1.7	3.5	0.0	94.8
No. of sties	2	1	1	1	2	1	1	1	1	1
LSD (0.05)	0.8	0.9	15.1	24.9	22.7	11.0	6.5	4.8	4.2	9.6

Table 5. Field evaluation of spring wheat lines with putative Midge-resistance in 2000.

Entry	Yield (kg/ha)	Spike emergence (d)	Physiological maturity (d)	Plant height (cm)	LBL (i-9)	Lodging score (1-9)	Test weight (kg/hL)	1000- Kernel weight (g)	Midge damage seed (%)	Ferulic acid content- 10DPA (mg/100g)
AC Barrie	3775	60.4	99.2	99	5	1.9	79.9	33.5	5	244
Laura	3726	60.6	100.3	99	5	2.9	79.1	33.3	6	297
AC Elsa	4047	59.6	99.0	99	4	1.9	79.3	34.0	8	265
Roblin	3659	56.8	97.0	94	7	2.0	77.7	33.9	12	253
CDC Teal	3771	59.9	98.1	96	5	1.7	78.4	32.9	15	245
700	3829	60.1	98.7	99	5	1.2	78.6	32.8	12	251
701	3756	60.1	97.4	98	4	1.9	79.4	32.5	9	267
702	3623	59.6	99.3	100	5	1.8	79.5	31.3	8	263
703	3888	60.0	99.9	99	5	2.5	79.3	33.8	10	268
704	3797	60.7	98.2	100	5	1.7	78.2	31.9	9	262
705	3701	60.1	99.2	98	6	3.2	79.3	32.9	11	276
706	3647	60.3	98.9	99	5	1.8	79.0	32.7	9	254
707	3717	60.1	99.4	103	6	1.0	80.1	37.2	10	259
708	3941	59.3	98.7	97	5	1.9	80.0	33.6	12	289
709	3983	60.0	99.8	102	5	2.2	80.0	33.5	8	270
710	3743	59.8	99.2	100	5	1.6	79.0	32.5	13	257
711	3762	59.9	99.7	99	5	2.1	78.9	33.8	16	241
712	3871	59.3	98.6	99	4	2.2	78.2	33.9	16	278
713	3861	59.7	99.5	100	4	2.4	79.9	32.4	11	272
714	3694	59.6	98.4	100	5	2.0	79.6	33.2	11	273
715	3625	60.1	98.8	100	5	2.3	79.2	32.8	7	262
716	3773	59.0	98.3	97	4	2.0	79.7	29.7	11	258
717	3588	58.8	99.3	96	5	1.9	79.4	31.2	12	269
718	3843	59.8	97.9	100	4	2.8	79.6	33.0	8	262
719	3782	58.9	98.4	98	4	2.9	80.1	31.4	11	243
720	3706	59.9	97.8	99	4	1.5	78.7	30.7	11	244
721	3781	60.0	97.2	100	5	2.1	78.9	33.6	13	234
722	3807	59.4	98.5	98	4	1.3	79.1	33.6	11	270
723	3841	59.3	99.0	96	4	1.7	79.1	31.3	12	247
724	3762	59.8	99.1	96	5	1.7	79.0	32.0	13	252
725	3408	59.4	98.3	101	5	2.9	78.6	34.0	13	269
726	3484	59.5	98.0	96	4	1.4	78.5	33.5	11	248
727	3699	59.9	98.2	99	5	2.1	79.5	35.0	10	251
728	3637	60.6	98.4	98	5	1.4	78.1	33.8	10	258
729	3472	59.3	98.5	98	4	2.6	78.6	33.8	8	252
730	3773	59.1	97.6	101	5	2.7	79.1	32.1	7	291

Table 6. Field evaluation of spring wheat lines with putative Midge-resistance in 2001.

Entry	Yield (kg/ha)	Spike emergence (d)	Physiological maturity (d)	Plant height (cm)	Test weight (kg/hL)	1000-kernel weight (g)	Ferulic acid content-10DPA (mg/100g)
AC Barrie	2554	56.8	91.0	78.3	81.1	32.5	211.9
Laura	2670	57.3	92.3	76.7	81.6	33.3	240.0
AC Elsa	2473	57.5	91.5	78.3	81.8	35.3	212.7
CDC Teal	2460	56.5	90.5	79.0	80.3	32.5	215.9
W01228	2421	56.5	90.5	77.3	80.3	31.7	214.3
W01229	2603	56.7	91.5	79.2	81.3	33.5	196.9
W01230	2346	56.2	90.8	75.7	81.0	31.4	224.3
W01231	2549	56.5	91.8	77.7	80.9	31.1	227.9
W01232	2546	56.3	92.0	81.3	81.2	32.6	223.3
W01233	2511	56.0	91.0	76.8	81.3	30.7	235.1
W01234	2369	56.2	90.5	80.8	80.3	31.7	224.2
W01235	2314	56.2	90.3	78.5	79.4	29.8	228.2
W01236	2484	56.7	90.8	79.5	80.7	32.4	230.8
W01237	2650	56.5	91.3	79.7	81.8	30.2	239.5
W01238	2320	56.0	90.8	77.7	80.7	30.3	218.1
W01239	2771	57.5	92.0	80.8	82.9	35.7	194.2
W01240	2425	56.8	90.3	80.2	83.4	35.1	251.2
W01241	2612	58.0	92.0	82.8	81.6	34.0	237.4
W01242	2497	56.5	90.8	81.3	82.9	36.6	212.7
W01243	2370	58.0	92.5	77.8	82.8	35.0	234.1
W01244	2550	54.5	90.8	78.3	82.0	35.6	231.2
W01245	2553	57.3	91.3	81.8	81.7	35.5	214.2
W01246	2563	57.7	91.5	80.7	82.5	33.9	197.9
W01247	2513	57.2	90.5	79.0	82.3	35.7	229.3
W01248	2313	56.2	91.5	78.5	82.3	37.0	229.3
W01249	2699	57.7	90.8	81.2	81.3	35.8	217.2
W01250	2414	55.7	90.8	71.5	82.4	34.4	218.4
W01251	2481	56.7	91.0	79.7	81.4	34.2	220.6
W01252	2574	57.2	92.3	79.5	80.6	36.0	207.7
W01253	2646	57.2	91.5	81.2	81.3	34.5	208.6
W01254	2540	56.7	91.3	81.7	80.5	32.6	207.0
W01255	2593	57.5	92.5	81.7	81.8	34.6	219.8
W01256	2568	57.0	91.3	81.2	81.4	35.5	218.9
W01257	2472	56.3	91.0	77.2	80.3	32.8	214.1
W01258	2655	56.8	91.6	81.7	80.8	32.3	200.2
W01259	2473	55.8	90.8	80.5	81.2	33.7	211.6
No. of stiles	4	3	2	3	1	1	2
LSD (0.05)	295	0.9	1.5	4.4	0.8	2.6	20.8

Table 7. Field evaluation of spring wheat lines with putative Midge-resistance in 2002.

Entry	Yield (kg/ha)	Spike emergence (d)	Physiological maturity (d)	Plant height (cm)	Test weight (kg/hL)	1000- kernel weight (g)	Midge damaged seed (%)	Non- damaged seed (%)	Ferulic acid content- 10DPA (mg/100g)	Ferulic acid content- maturity (mg/100g)
AC Barrie	3435	51.5	91.0	72.7	78.5	35.8	9.7	90.4	220.3	67.8
AC Elsa	3223	51.2	91.3	73.8	79.0	36.0	6.8	93.2	242.0	67.2
AC Intrepid	3161	48.8	90.0	71.0	78.1	37.7	7.4	92.6	208.8	62.4
CDC Bounty	3478	51.7	90.0	75.3	81.2	38.1	15.8	84.3	213.2	67.5
AC Abbey	3161	51.0	92.5	64.8	78.9	37.1	9.8	90.2	220.6	67.5
W02605	2651	50.8	90.5	71.2	78.8	37.9	9.4	90.7	209.2	60.4
W02606	3475	50.0	90.7	73.7	79.2	37.2	6.2	93.8	220.3	64.8
W02607	3342	52.0	93.0	71.7	77.8	36.6	6.9	93.1	227.1	68.4
W02608	3361	51.7	92.3	71.8	79.0	36.2	6.0	94.1	245.3	64.2
W02609	3086	49.8	89.7	68.0	79.6	35.1	14.5	85.6	228.4	56.8
W02610	3229	51.2	92.2	71.3	78.8	34.6	8.0	92.1	217.5	55.5
W02611	3223	51.7	90.3	67.7	78.8	33.6	9.1	91.0	261.1	57.6
W02612	3086	49.7	88.7	68.2	78.3	34.9	6.5	93.5	225.0	68.6
W02613	3024	51.0	91.0	73.3	76.7	35.0	12.3	87.8	263.2	63.6
W02614	2910	50.5	92.3	71.8	79.0	33.1	3.1	91.9	207.4	56.3
W02615	2752	49.7	86.2	72.0	78.3	38.4	6.0	94.0	244.1	59.7
W02616	3707	50.5	92.2	71.8	81.1	37.6	14.4	85.7	216.4	66.2
W02617	3019	50.7	89.0	76.3	80.1	39.8	9.3	90.8	232.4	60.3
W02618	2800	49.2	89.0	69.7	80.0	32.4	11.1	89.0	223.3	54.4
W02619	2952	48.7	88.8	67.3	80.3	33.9	10.0	90.1	219.9	54.2
W02620	3085	50.7	91.3	70.8	78.8	35.5	6.1	94.0	233.2	57.4
W02621	3242	49.7	90.0	67.5	78.2	35.5	11.1	89.0	221.4	56.2
W02622	3051	50.0	90.0	71.5	78.6	38.1	9.5	90.6	214.3	52.3
W02623	3013	49.0	88.2	69.3	76.9	37.3	4.2	95.9	210.2	63.1
W02624	2842	48.3	87.2	70.5	77.0	37.7	8.9	91.2	204.0	58.7
W02625	3002	49.0	89.3	71.5	78.4	39.4	5.6	94.4	213.9	62.1
W02626	3140	51.2	90.2	73.8	78.2	35.9	11.1	89.0	235.1	58.3
W02627	3052	48.2	86.8	69.8	77.5	38.2	7.0	93.1	212.2	65.1
W02628	3086	48.3	88.5	70.8	77.7	37.9	5.6	94.5	217.0	59.9
W02629	3047	48.5	87.2	71.0	77.2	37.5	6.4	93.6	218.6	66.7
W02630	3007	49.7	87.0	71.3	77.9	35.7	11.2	88.9	236.5	45.3
W02631	3229	49.2	89.7	75.3	78.3	37.1	3.8	96.3	209.3	60.7
W02632	3190	48.8	86.5	74.3	77.6	38.4	11.7	88.3	211.0	60.8
W02633	3138	48.8	90.2	71.7	78.2	37.7	4.0	96.0	186.5	52.7
W02634	2813	48.7	88.7	69.3	77.0	37.1	5.2	94.9	211.6	61.5
W02635	3182	49.0	88.5	73.5	78.5	37.9	15.6	84.4	227.6	60.7
No. of sties	3	3	3	3	2	2	1	1	2	2
LSD (0.05)	421	1.6	2.3	6.0	1.0	1.8	5.8	8.2	21.3	8.2

